TABLE 30. ESTIMATES OF DRY WEATHER PLANT SLUDGE VOLUMES PRODUCED FROM THE TREATMENT OF DILUTE EFFLUENTS PUMPED BACK AFTER DEWATERING CSO TREATMENT SLUDGES

| CSO Treatment Process | Dilute Effluents Pumped Back | | | Equivalent Sewage | | | Sludge Flow Produced | | | | | |
| | cu m/day | MGD | Solids mg/l | cu m/day | MGD | Solids mg/l | Primary | | Activated | | Total | |
							cu m/day	MGD	cu m/day	MGD	cu m/day	MGD
Storage-Sedimentation	757,000	200	347	1,325,000	350	200	3,217	0.85	24,640	6.51	27,858	7.36
Dissolved-Air Flotation	492,050	130	84	227,000	60	200	568	0.15	4,353	1.15	4,920	1.30
Screening/DAF	4,390,000	1160	1,321	23,993,000	7660	200	70,780	18.7	542,012	143.2	612,792	161.9
Contact Stabilization	3,066,000	810	331	6,245,000	1650	200	15,254	4.03	116,956	30.9	132,096	34.9
Trickling Filter	643,000	170	170	530,000	140	200	1,287	0.34	9,841	2.60	11,128	2.94

Table 28 were converted to equivalent domestic sewage by adjusting their suspended solids content to 200 mg/l. Then the sludges produced from treating the dilute effluents pumped back are estimated by assuming a primary sludge production of 2240 cu m (gal.) (5% solids) per million cu m (MG) of adjusted flow and 18,700 cu m (gal.) (1% solids) of waste activated per million cu m (MG) of adjusted flow. These calculations are summarized in Table 30.

1. Hydraulic Considerations

It may be seen from Table 30 that the estimated sludge volumes produced varied widely with the CSO treatment sludges dewatered, and this variation is attributable to the quality of the dilute effluents bled/pumped-back. That is, the poorer the dilute effluent quality, the greater the sludge volume produced by the dry-weather plant, which is to be expected. For example, the data in Table 30 show that the quality of the dilute effluent from screening-flotation is of appreciably poorer quality than those of the other dilute effluents investigated, and the sludge volumes produced as a result of treating the dilute effluents from screening-flotation are correspondingly appreciably greater than those from any of the other CSO treatment methods.

It was previously established that the daily design volume of sludge (primary plus activated) to be handled by the hypothetical dry-weather sludge handling facilities is 3.6×10^5 cu m/day (96 MGD). Comparing this value with the additional sludge volumes expected and shown in Table 30 indicates that three of the five sludge volumes shown (from storage - sedimentation, dissolved air flotation and trickling filtration) can be intermittently handled by the dry-weather sludge handling facilities, assuming that the dry-weather sludge handling facilities are below design conditions (which is a reasonable assumption).

On the other hand, it appears that two of the five sludge volumes in Table 30 (screening/DAF and contact stabilization) would hydraulically overload the dry-weather sludge handling facilities. Closer examination of Table 30 shows that the two sludge volumes in question were derived from dilute effluents comparatively higher in quantity and poorer in quality than the other dilute effluents. This lends emphasis to the importance of performing the CSO treatment methods and the CSO treatment sludge dewatering method as efficiently as possible so as to permit the bleed/pump-back of dilute effluents to the dry-weather treatment plant. For example, further investigation (12) into the dewatering tests performed on the sludges from screening/DAF of CSO yielding the dilute effluent qualities shown in Tables 21 and 30 indicate that the thickening-filtration dewatering was accomplished without the aid of chemicals. The use of chemical conditioning would probably improve the dilute effluent quality permitting bleed/pump-back to the dry-weather plant with an appreciable reduction in the amount of sludge produced for further treatment by the dry-weather sludge handling facilities.

2. Solids Loading Considerations

For our hypothetical dry-weather plant, the design dry-weather solids to be handled (primary plus activated) has been established at 5.3×10^6 kg/day (11.7×10^6 lb/day). The additional sludge solids produced by pumping back the dilute dewatering effluents (whose estimated sludge volumes are shown in Table 30) are estimated by assuming a primary sludge concentration of 5% and a waste activated sludge concentration of 1%. A summary of the additional sludge solids expected is shown in Table 31.

The conclusions drawn from the solids information contained in Table 31 are similar to those derived from Table 30 with regard to the hydraulic considerations evaluated, namely,

a. Comparison of the sludge handling facility design solids loading of 5.3×10^6 kg/day (11.7×10^6 lb/day) with the additional solids loadings shown in Table 29 indicates that three of the five solids loadings shown in Table 30 (from storage-sedimentation, dissolved-air flotation and trickling filtration) can be intermittently handled by the dry-weather sludge handling facilities, assuming that the dry-weather sludge handling facilities are below design conditions (which is a reasonable assumption).

b. On the other hand, it appears that two of the five solids loadings in Table 30 (screening/DAF and contact stabilization) would create a solids overload problem for the dry-weather sludge handling facilities. However, as indicated previously, it is felt that this problem may be minimized by more efficient CSO treatment and CSO treatment sludge dewatering performance, thereby permitting the satisfactory bleed/pump-back of the dilute effluents to the dry-weather plant.

BOD, heavy metals, PCB and pesticide data on the dilute effluents from dewatering CSO sludges were not discovered in the literature, and therefore, no comment is made at this time regarding organic overload, toxicity to treatment, and sludge handling efficiency due to these pollutants.

In summary, it may be concluded that bleed/pump-back of CSO treatment sludges to the dry-weather plant does not appear to be a viable or practical solution on a generalized basis. If 100% of the CSO volume was treated and generated sludge, it would result in gross overloading of the dry-weather treatment plant and the dry-weather sludge handling facilities. The most limiting aspect of bleed/pump-back of sludge through the treatment plant and sludge handling facilities is the solids loading (to the final clarifiers and the digesters). On the other hand, bleed/pump-back of the dilute residuals from on-site dewatering of CSO treatment sludges to the dry-weather plant appears to be practical and warrants further considerations where applicable. However, it must be stressed that actual evaluation of the feasibility of bleed/pump-back of CSO sludges must be completely evaluated for each individual site. The potential problems associated with transport of a gritty sludge, solids overload to the treatment and sludge handling processes and lower

TABLE 31. ESTIMATED SOLIDS TO THE DRY WEATHER SLUDGE HANDLING FACILITIES
FROM THE TREATMENT OF DILUTE EFFLUENTS OBTAINED FROM CSO SLUDGE DEWATERING

CSO Treatment Process	Primary Sludge		Activated Sludge		Total	
	$kg/dayx10^{-6}$	$lb/dayx10^{-6}$	$kg/dayx10^{-6}$	$lb/dayx10^{-6}$	$kg/dayx10^{-6}$	$lb/dayx10^{-6}$
Storage-Sedimentation	0.16	0.35	0.25	0.54	0.40	0.89
Dissolved-Air Flotation	0.03	0.06	0.05	0.10	0.07	0.16
Screening/DAF	3.54	7.79	5.42	11.94	8.96	19.73
Contact Stabilization	0.76	1.68	1.17	2.57	1.93	4.25
Trickling Filter	0.06	0.14	0.10	0.22	0.16	0.36

NOTE: Sludge volumes used for the calculations were obtained from Table 29.

treatment plant efficiency must be evaluated at each site and cost-effective-
ness of bleed/pump-back determined.

SECTION VI

EFFECT OF HANDLING CSO TREATMENT
RESIDUALS BY SEPARATE SLUDGE HANDLING FACILITIES

INTRODUCTION

The most feasible method for handling specific CSO treatment residuals must be evaluated on an individual basis. As indicated in the previous section, bleed/pump-back is not a viable solution in most situations due to problems of transport in pipelines and potential solids overload in the various dry-weather treatment processes. Once evaluation indicates that bleed/pump-back is not an acceptable alternative, then separate sludge handling facilities must be provided. The processes must be capable of handling the specific characteristics associated with CSO sludges. They also must be sufficiently flexible for anticipated intermittent operation. Once applicable processes for sludge handling are identified, treatment trains can be established to integrate all phases of sludge handling. It must be emphasized at this point that the systems proposed in this section are generally suited for CSO sludges, however design of a specific system must be considered on an individual basis where much different schemes may be appropriate. The last step in evaluation of separate sludge handling facilities is location. There are essentially three systems which can be considered: 1) transportation to parallel facilities at the dry-weather plant, 2) transportation to a centrally located CSO sludge handling site and 3) satellite sludge treatment. The advantages and disadvantages of each technique are presented.

This section has been divided to consider several aspects of sludge treatment for CSO residuals individually. The limitations imposed by the nature of CSO sludges are presented first. Then a brief discussion of various sludge handling processes is included, followed by development and technical evaluation of viable sludge handling alternatives. The final portion of the section discusses alternative locations available for treating the sludge.

SPECIAL HANDLING REQUIREMENTS FOR CSO TREATMENT RESIDUALS

The characteristics of CSO treatment residuals directly affect the number of processes which can be used for handling these sludges. Specific attention must be given to the high grit content and low volatile solids concentration of these materials. In addition, the wide variation in frequency and volume of each occurrence requires that the sludge handling process be flexible enough to handle intermittent operation.

The information indicating the effects of high grit and low volatile solids content has been presented previously throughout sections IV and V. The following is a summary of this information for convenience:

a. That substantial amounts of solids are transported to the dry weather plants under wet weather conditions is substantiated by significant data available from the literature (17). For example, presented in Table 18 were data showing the quantities of grit collected during dry and wet weather periods for various United States installations. The data in Table 18 showed that the grit volume ratio of wet to dry weather was appreciable, with the highest ratio at 1800 times the average dry weather grit production.

b. The literature (9) also indicates that often the stormwater solids contribute a large increase in fine solids (silt) which is too fine to be removed in the grit chambers and results in overloading the primary sedimentation basin to the extent that chain and flight collectors are sometimes buried and unable to function.

c. It was further shown that the volatile solids contents of the sludges from the various CSO treatment methods were significantly to appreciably lower than that for dry-weather municipal sludges. The higher volatile solids contents were observed for the sludges derived from the CSO biological treatment methods. This was expected because the biological treatment methods used were preceded by treatment steps which removed the major portion of the grit and inert solids present in the raw CSO, whereas the physical and physical-chemical treatment methods used treated raw CSO with little or no preliminary treatment for inert solids removal.

d. It was found that the net effect of the excess inert solids in the CSO sludges (when bled/pumped-back to the DWF plant) was to contribute to the solids overload on the dry weather treatment and sludge handling facilities. Moreover, it was indicated that alternative CSO sludge treatment, either on-site or in additional parallel facilities at the DWF plant, would require additional capacity to handle the excess inert solids load.

It can then be proposed that the high grit and low volatile solids content of the CSO treatment residuals will also have a direct bearing on the effectiveness of various sludge handling processes. The large amount of inert material will require compensation in the equipment designs which are based on solids loading such as thickening, filtration, lagooning, sand drying beds, centrifugation, etc. Also, grit and other inert solids would detrimentally affect digestion (aerobic or anaerobic) facilities because the possibility of settling of those solids in the digesters, thereby occupying valuable space. The heavy solids loading could also cause mechanical complications in some equipment.

The low volatile solids content will have the most effect on the processes which utilize the organic substrate. Of special concern are digestion

processes, since the lower organic loadings will reduce the efficiencies of removal, and incineration, since many of the CSO residuals have significantly lower heat values (12).

The intermittent nature and wide variations in flows of CSO sludges could pose problems when many common sludge handling processes are considered. Most sludge systems are designed for operation on a continuous flow-through basis which is generally not possible when dealing with CSO sludges (unless extensive holding basins are provided). The volumes of CSO sludge generated will vary with the storm intensity and duration, time between storms, process efficiency, etc. Therefore, either additional holding (storage) capacity is needed or the unit processes must be designed to handle maximum anticipated flows and still effectively process lesser amounts. Several sludge handling processes, notably digestion, may be adversely affected by the intermittent operation. It is important to consider these factors when the sludge handling processes are evaluated.

From the foregoing discussion, several evaluation criteria can be established and they should be considered when choosing applicable sludge handling methods for CSO residuals. The following considerations are important:

1. Is the process design established by solids loading criteria?

   If so, the large volume of inert solids may adversely affect the system operation and additional capacity will be required.

2. Will the volume of inert solids affect the operation of the process?

   If so, then again additional capacity may be needed which may be detrimental to the process efficiency.

3. Is the process dependent on a specific amount of organic constituents for proper or efficient operation?

   If so, then the unusual ratio of volatile solids to inert material may cause severe problems in the overall design of the system.

4. Will intermittent use adversely affect the operation or efficiency of the process?

   If so, then the degree of lower efficiency must be established and the process evaluated from this criterion.

5. Will overdesign of the system (to handle maximum flow rates) adversely affect the process operation under lower loading rates?

   If so, then use of large storage basins preceding the sludge handling system or process are mandatory. If space for holding is not available, the given process may not be applicable.

Therefore the individual sludge handling processes must be reviewed with these criteria in mind when considering their use for CSO treatment residuals.

SLUDGE HANDLING PROCESSES

General Sludge Handling Systems

In general, sludge handling processes can be grouped according to the general phases shown in Figure 7. Various combinations of these processes can be utilized, to provide the overall sludge handling schematics. Basically the potential flow schematics are as follows:

1. (Conditioning)* → Thickening → Stabilization → (Dewatering) → Disposal
2. (Conditioning) → (Thickening) → Dewatering → Reduction → Disposal
3. (Conditioning) → Stabilization → Thickening → (Dewatering) → Disposal
4. (Conditioning) → Stabilization → Disposal

* parentheses indicate optional process

Individual processes can now be evaluated and the appropriate systems developed for CSO treatment residual handling.

Conditioning

Conditioning is used to pretreat the sludge to allow more effective thickening or dewatering. The processes used can include chemical addition of polymer, lime, ferric chloride or alum, among others, or heat treatment. Effective conditioning can increase the efficiency of the processes when applied properly. However, choice of proper chemicals for this type of conditioning is dependent upon individual sludge characteristics. If there are significant variations in sludge quality, as are common with CSO treatment residuals, then the needed chemical dosages will change.

If provision cannot be made to correct the dosages utilized in the field, which is difficult with intermittent CSO generation, then the effectiveness of chemical conditioning can be severely reduced. Heat treatment can also be utilized with temperatures from 149-260 °C (300-500 °F) and pressures of 10.2-27.2 atm. (150-400 psig)(22). The treatment breaks up cell masses and improves dewatering characteristics. However, the resulting supernatant is highly polluted with various organics and requires that additional capacity be available at wastewater treatment facilities. In addition, the process is extremely energy intensive which may cause future problems.

Thickening

Thickening removes the major portion of the liquid in sludge and is often the initial step in sludge dewatering. Thickening is applicable to the dewatering of CSO sludges, and in particular, gravity thickening equipment is usually employed for sludges derived from physical and physical-chemical CSO treatment methods, whereas flotation thickening is normally more amenable to thickening sludges emanating from biological treatment methods.

Centrifugal thickening may also be applicable to some CSO sludges, however prior grit removal is necessary to prevent excessive wear on the centrifuge

GENERAL TREATMENT PROCESS

Conditioning	Thickening	Stabilization	Dewatering	Reduction	Disposal
Chemical	Gravity	Anaerobic digestion	Vacuum filtration	Incineration	Sanitary landfill
Heat	Dissolved-air Flotation	Aerobic digestion	Centrifugation	Flash drying	Ocean
	Centrifuge	Chlorine oxidation	Drying beds	Wet air oxidation	Land application
		Lime treatment	Drying lagoons	Pyrolysis	Land reclamation
		Heat treatment	Filter press	Cyclonic furnace	
		Composting	Moving screen	Electric furnace	
			Capillary belt		
			** DCG/MRP		

GENERAL TREATMENT TRAINS

1. (Conditioning)* → Thickening → Stabilization → (Dewatering) → Disposal

2. (Conditioning) → (Thickening) → Dewatering → Reduction → Disposal

* Parentheses indicate optional process.

** Rotating Gravity Concentrators

Figure 7. Sludge handling systems.

mechanism.

Stabilization

In most cases, stabilization of the sludges is required before ultimate dis-
posal in order to minimize organic solids mass, health hazards and nuisance
conditions. In fact, where final disposal is on land [50% of U.S. installa-
tions (22)], such as by sanitary landfill, cropland application and land re-
clamation, it is essentail that sludges be stabilized prior to spreading on
land.

Stabilization, therefore, minimizes nuisance conditions by decomposing
organic solids to a more acceptable stable form and minimizes health hazards
by reducing or eliminating pathogenic organisms. Stabilization processes
and equipment available include anaerobic and aerobic digestion, heat treat-
ment, composting and chemical treatment (chlorine oxidation and lime treat-
ment). Some of these stabilization processes are established and some are
experimental· Further discussion regarding them and their applicability
for handling CSO sludges is included.

Anaerobic and Aerobic Digestion - Both anaerobic and aerobic digestion are
established processes and because of the current energy shortage are in-
creasing in popularity; the former because of the potential benefits of
methane production and the latter because it can produce exothermic con-
ditions. These processes are applicable for handling CSO sludges derived
from biological treatment methods and the associated equipment required
should be located at the dry weather treatment plant along with the CSO
biological treatment equipment so as to be able to keep the "CSO digesters"
viable with dry-weather sludge between storms. It may be evident that
these processes are not applicable at remote on-site CSO physical and
physical-chemical facilities where the means for keeping the processes viable
between storms is not existent.

Heat Treatment - Heat treatment of sludges has seen rapid growth in recent
years and includes the following: pasteurization, low pressure oxidation
(Sterling Drug) and the Porteous heat treatment process. At this time, the
heat treatment of sludges has many vigorous advocates and equally vigorous
opponents. Usual complaints include failure of equipment, excessive cost
and high supernatant BOD and color. Because of the impact of this process
on cost and the unknown effect of high supernatant BOD on organically over-
loading the dry-weather plant, this process will not be further considered
as a CSO sludge stabilization alternative.

Composting - Composting of sludge has not been widely applied in North
America. Of the 18 composting plants constructed in the U.S. between 1951
and 1969, few are currently operated and many of these are operated intermit-
tently. The primary problem has been the lack of a market for the stable
product to offset the cost of the process and make it economical. Composting
will not be further considered for handling CSO sludges.

Chemical Stabilization - Chemical stabilization processes include chlorine
oxidation and lime stabilization. The Purifax process oxidizes sludge with

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heavy doses of chlorine (about 2000 mg/l) and produces a stable and sterile sludge which is low in pH (about 2). The treated sludge dewaters well on sandbeds and is amenable to vacuum filtration after conditioning. Chlorine cost only is about $5.50/metric ton dry solids ($5/ton). Other operating and capital costs would increase this figure. The primary concern with this process is that the drainings from the treated sludge contain high concentrations of chlorinated compounds which may be toxic. Because of this concern and the possibility of ultimate disposal on land, further consideration of this process for handling CSO sludges will not be made.

The lime stabilization process is also a chemical stabilization process designed to reduce many of the harmful properties of sludges. The process involves addition of slurried calcium hydroxide to a pH greater than 11-12 and continued mixing of the solution for thirty minutes. This time period allows the slower reacting lime to hydrolyze and provides contact for pathogen destruction. A schematic of the typical process is shown in Figure 8. Previous studies (32, 33) on the subject have indicated that this procedure effectively reduces the indicator organisms for bacterial pollution up to 99 percent and significantly reduces nuisance odors (34). In addition, the dewatering characteristics of the sludge are markedly improved. Investigators (34) concluded that lime stabilized sludge is as safe to handle as that produced from conventional anaerobic digesters. However, there can be problems with lime stabilized sludge if proper disposal methods are not utilized. The high pH of the sludge is not permanent and as the pH decreases during the degradation process, odor and bacteria problems may reoccur. Excess lime dosages and proper disposal can retard or eliminate the problem.

Lime stabilization seems to be quite adaptable to CSO sludge treatment for several reasons. First, the process is flexible. It can be used intermittently with sludges of a wide variety of characteristics. The process control is commonly performed utilizing pH measurements so that operator intervention is minimal. The anticipated total capital investment is lower due to simple operation and shorter detention times than other stabilization techniques. If necessary, a portable treatment unit could be developed for use. This type of system may be used to augment dry-weather sludge handling facilities when not required for CSO sludge treatment. However, the lime dosages required are high and this cost must be considered. Previous studies (35) have indicated that lime dosages range from 102-208 g $Ca(OH)_2$ per kg of dry solids and operating and maintenance costs are estimated to be $9-$19 per metric ton ($8-17 per ton) of dry solids. In addition, direct land application of lime stabilized sludges requires hauling large volumes of liquid sludge which may not be practical in some situations. In these situations, further dewatering using centrifugation or vacuum filtration is a necessary subject for further study. However, it is anticipated that with lime stabilization, further chemical conditioning requirements would be minimal since the lime addition significantly improves sludge dewatering capabilities. Another advantage of using lime stabilization is the reduction of potential odor prior to further handling. This aspect may be important if storage for any length of time is required.
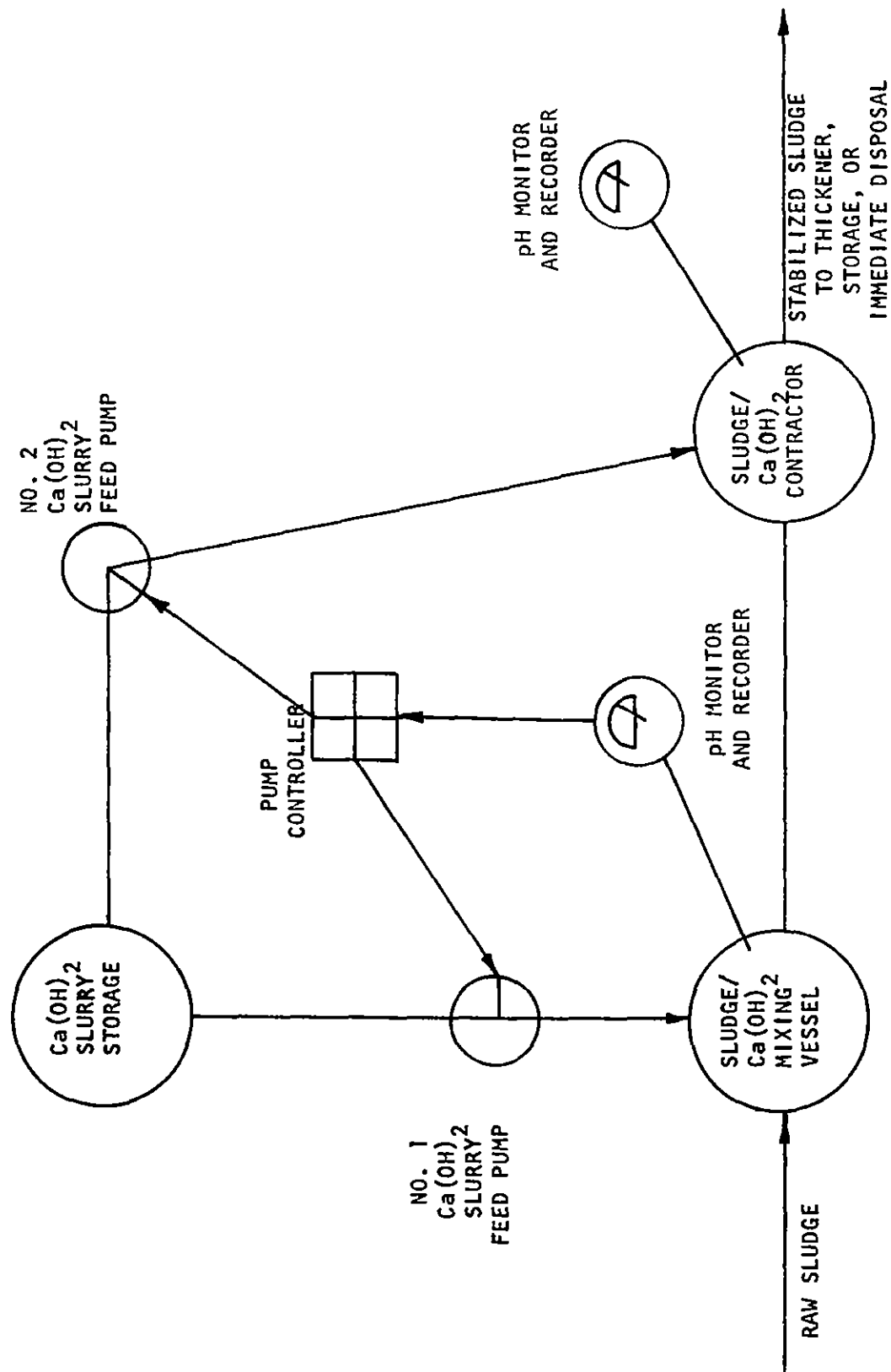
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Figure 8. Lime stabilization process conceptual flowsheet (35).

Dewatering

Dewatering is used to remove additional moisture from the sludge (50-90%) to produce a damp cake (22, 36). The devices utilize several methods including natural evaporation and percolation plus mechanical techniques such as filtration, squeezing, vacuum withdrawal, centrifugation and compaction. Referral to Figure 7 indicates that there are many potential techniques available for dewatering. When considering these processes with respect to CSO sludges, some can be eliminated due to apparent operational problems. Space restrictions will eliminate use of both drying beds and drying lagoons, in most cases. Devices such as moving screens, capillary systems and rotating gravity concentrators (DCG/MRP) are new systems which have not been defined with respect to their applicability to the high grit content of CSO sludges. The techniques may be appropriate, however, further investigation would be needed prior to their use.

More conventional techniques include filter press, vacuum filtration and centrifugation. Use of a filter press is desirable if incineration or other combustion technique is being utilized, otherwise it may be too expensive for CSO sludge dewatering. In addition, conditioning requirements and operator control needs may be greater. It may be more desirable to use vacuum filtration, which will provide a workable cake (approximately 20% solids) for landfill or land application. Preliminary studies (12) have indicated that dewatering thickened sludges by vacuum filtration was amenable to CSO sludges derived from contact stabilization. Centrifugation may also be an appropriate dewatering technique if the grit concentration will not cause extensive mechanical wear. It was indicated that the use of thickening and centrifugation was applicable to the CSO sludges emanating from treatment by screening/DAF and trickling filtration. In some instances it was indicated that some CSO sludges may be most effectively dewatered by centrifugation alone (without pre-thickening). These included sludge from storage-sedimentation and from dissolved-air flotation alone (25) (see Table 28).

Reduction

In some cases reduction can be utilized as a stabilization and/or disposal process. Several types of processes can be utilized as outlined in Figure 7 and these can be further divided into new or established types. Pyrolysis and the use of cyclonic and electric furnaces are new techniques which have been used mainly on a small scale basis. The effects of the high grit and low volatile solids content is not readily predictable. However, it is speculated that the same features which affect the use of incineration for CSO sludge handling are applicable in these systems.

Incineration can be used to reduce the sludge to ash after thickening and dewatering. Incineration although costly, is receiving increased attention as an alternative with decreasing land availability and the possibility of more stringent standards for land disposal. However, wastewater treatment sludges have low heat values in comparison to common fuels to the extent that combustion is not self-sustaining unless extremely high solids contents are reached in feed cakes. Often an auxiliary fuel is required, if waste-

water sludges are incinerated alone. The heat value for typical dry-weather activated sludge solids is 3563 cal/gm (6413 BTU/lb) as compared to gasoline with a value of 11,100 cal/gm (19,980 BTU/lb). Furthermore, it was observed (12) that the heat value of most other CSO treatment sludges was even less. The average heat value for CSO sludges from physical and physical-chemical treatment was 2032 cal/gm (3657 BTU/lb), whereas that for similar dry-weather sludges is estimated at 4581 cal/gm (8246 BTU/lb) (27). This difference in heat value is attributed to the higher inert and low volatile solids content of the CSO treatment sludges in question. On the other hand, the heat value of the biological sludges from CSO biological treatment was comparable to that for the dry-weather biological sludges, and that was expected because of the similar solids characteristics.

Because the heat value for CSO sludges is relatively low, the cake solids in the feed must be proportionately higher to avoid the use of auxilliary fuel. The energy and capital costs of obtaining a sufficient solids concentration in the feed cake may be prohibitive. If auxilliary fuel is utilized, in the light of the increase in energy cost and the current energy shortage, incineration would not be a viable method for handling CSO sludges at this time. However, interest in using incineration may be revived if the combined incineration of solid waste residues and wastewater sludges are incorporated with energy recovery as a prime feature.

Wet air oxidation is the final technique which may be used for sludge reduction. It is used at higher temperatures and pressures than heat treatment and theoretically oxidizes any materials capable of burning in water at temperatures of 121-371 ^{o}C (250-700 ^{o}F). Preliminary thickening and dewatering are not necessary, however it is necessary to provide disposal for the oxidized material. The main disadvantages associated with this technique are the high energy cost and the associated problems due to intermittent operation. High pressure and temperature operations should be run as continuously as possible to alleviate start-up problems and energy loss.

Disposal Techniques

Disposal techniques involve either the land or oceans. However, recent regulations have restricted ocean dumping, so that only land disposal remains. Three techniques are applicable; land reclamation, land application and landfill. Land reclamation is most restrictive since it requires that land needing to be reclaimed (such as abandoned strip mines) be located near the sludge generation site. This criterion will not generally be met with regard to CSO sludges. Land application does pose a viable solution for disposal and has been considered in depth in Section VIII. Further discussion is not included here.

Landfilling of sludges and other residual by-products of municipal and industrial waste treatment is a major ultimate disposal alternative. A sanitary landfill accepting sludge must be designed in accordance with EPA "Guidelines for Land Disposal of Solid Wastes" (37) even if sludges are disposed of separately or along with municipal solid wastes. These guidelines are a result of increasing concerns for public health and environmental quality (38). The guidelines state that prior to landfilling, (a) sludges

must be stabilized (ie. digestion, lime, heat etc.) to prevent odor problems and reduce health hazards and (b) sludges must be dewatered to eliminate leachate migration.

A sanitary landfill must be managed so that wastes are systematically deposited and covered with soil to control environmental impacts within defined limits. Proper management consists of four basic operations (39): 1) wastes are added in a controlled manner in a prepared portion of the site; 2) the wastes are spread and compacted in thin layers; 3) the wastes are covered daily or more frequently, if necessary with a layer of soil; and 4) the cover material is compacted daily.

Proper site selection is an important step toward establishing an acceptable sanitary landfill operation. Some of the major factors which should be considered in site selection are (40): a) land requirements, b) waste haul distances, c) cover material, d) geology, and e) climate.

Important public health and nuisance aspects which must be considered in landfill operation are 1) vector control, 2) water pollution, 3) odors, and 4) gas production (40).

EPA guidelines require that a program must be developed and implemented to provide for adequate monitoring of landfills accepting sludges (38). This plan would include groundwater observation wells, and surface runoff collection basins to measure pollutant migration from leachates or surface water.

DEVELOPMENT OF VIABLE TREATMENT SCHEMATICS

General

The first step in the development of viable treatment schematics is to identify those processes which are applicable to possible use for CSO sludge handling. Once this has been accomplished, then various treatment trains can be identified and further evaluated from a space and preliminary economic standpoint.

Generally, the process elements comprising a CSO sludge handling system might include grit and low volatile solids removal, sludge dewatering, stabilization and ultimate disposal. The specific treatment train used will vary with the CSO treatment method employed and location and the ultimate disposal method used. For example, it has been shown that the grit and low volatile solids contents of CSO sludges are greater than those for dry-weather municipal sludges. Moreover, for the CSO treatment methods investigated, greater concentrations of grit and low volatile solids contents were associated with sludges from physical and physical-chemical treatment than from sludges derived from biological treatment. This was expected because the biological treatment methods (contact stabilization and trickling filtration) were preceded by treatment steps which removed the major portion of the grit and inert solids present in the raw CSO, whereas the physical and physical-chemical treatment methods (storage-sedimentation, DAF, screening/DAF and micro-

screening) treated raw CSO with little or no preliminary treatment for inert solids removal. Therefore, it would be expected that the sludges from physical and physical-chemical treatment might require provision for grit and low volatile solids removal whereas those sludges from biological treatment might not. Suitable equipment for grit removal includes: chain and flight grit removal devices, hydroclones, and the swirl concentrator (41). Hydroclones are commercially available for grit removal from sludges. The swirl degritter is a newly developed device (77) (78) (79).

Specific Processes for Use In CSO Sludge Handling

The previous discussion briefly identified various processes which could be used for handling CSO treatment residuals. Due to the discussion presented therein and evaluation of the question criteria outlined previously in this section, the following processes are considered to be potentially applicable to CSO sludge handling:

Conditioning:	Chemical treatment
Thickening:	Gravity thickening
Stabilization:	Lime stabilization Anaerobic digestion (in some cases)
Dewatering:	Vacuum filtration Centrifugation
Reduction:	None
Disposal:	Land application (LA) Landfill

Potential Treatment Schemes

As indicated, the individual treatment scheme chosen is determined by the specific characteristics of the CSO sludge to be treated. However, for generalization, the biological sludges can be grouped into one type and the physical or physical/chemical sludges into another. Another important consideration is the location of the sludge handling system, especially when biological treatment techniques are being considered. Usually, if biological systems are applicable, the treatment system and sludge handling facilities are located at or near the dry-weather treatment plant. When this is the case, a different flow schematic than that generally proposed may be desirable.

Combination of the processes chosen which may be applicable to CSO sludge handling yields the following ten alternatives:

1. Lime Stabilization → Gravity Thickening → Vacuum Filtration → Landfill
2. Lime Stabilization → Gravity Thickening → Vacuum Filtration → Land Application

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3. Lime Stabilization → Gravity Thickening → Land Application
4. Lime Stabilization → Land Application
5. Anaerobic Digestion → Gravity Thickening → Vacuum Filtration →
   Landfill
6. Anaerobic Digestion → Gravity Thickening → Centrifugation → Landfill
7. Anaerobic Digestion → Gravity Thickening → Vacuum Filtration →
   Land Application
8. Anaerobic Digestion → Gravity Thickening → Centrifugation → Land
   Application
9. Anaerobic Digestion → Gravity Thickening → Land Application
10. Anaerobic Digestion → Land Application

It is observed that centrifugation was not included as a thickening method
when lime stabilization was utilized. This is mainly due to the fact that
the large doses of lime used for stabilization should allow vacuum filtra-
tion to proceed easily, with a minimum of additional chemicals. Also these
schematics do not presently include provision for grit removal, so the
potential wear on a centrifuge might be a problem. Therefore, centrifugal
dewatering was not considered at this time. However, both vacuum filtration
and centrifugation were considered if anaerobic digestion was utilized as
the stabilization technique, since prior grit removal is generally included.
Chemical conditioning is anticipated to be needed and the chemical type can
be tailored to meet the optimum dosage for the given dewatering method.

Both landfill and land application have been considered as viable disposal
techniques, although land application can accept much more dilute sludges,
if transportation costs are not prohibitive.

Preliminary Evaluation of Schematics

Evaluation of the flow schematics given involves an initial comparison of
lime stabilization and anaerobic digestion. Considering operational vari-
ables plus cost and space requirements, the advisability of using lime
stabilization over digestion is indicated even when biological treatment
of CSO is utilized. For example, lime stabilization is less complex in
operation, less subject to upsets, can be more easily automated and is more
adaptable to intermittent operation (digestion process would have to be
kept viable between storms). Moreover, lime stabilization appears to require
less space. A lime sludge contact time of about 30 minutes is needed for
lime stabilization (42), whereas 10-15 days solids retention time is re-
quired for digestion (See Tables 22 and 23). From the standpoint of costs,
it appears that the cost of digestion is appreciably greater than that for
lime stabilization. For example, for a 37,850 cu m/day (10 MGD) sewage
treatment plant which produces a total sludge flow of approximately 254
cu m/day (0.067 MGD), the capital cost of a lime stabilization process
is estimated at $28,000, and this cost includes tankage, piping, chemical
feed system and automatic control instrumentation. On the other hand, the
construction cost for an anaerobic digestion system to handle the same
quantity of sludge is estimated at $800,000 and this cost includes sludge
heating, circulating and control equipment and control building (43). The
operating costs for digestion are also appreciably greater than those for
lime stabilization. For example, the total annual costs for anaerobic diges-

tion (including amortization) are estimated at $31 per metric ton dry solids ($28/ton) whereas those for lime stabilization are about $10 per metric ton dry solids ($9/ton) (44). From the above discussion, it is evident that lime stabilization is a promising method for handling the unique CSO treatment sludges. It should be recognized that lime stabilization is not an established sludge handling method and demonstration of its application for treating CSO treatment sludges should be pursued to obtain basic design and operating criteria and further investigation is recommended.

Sludge dewatering by thickening, where economically feasible, should be performed after lime stabilization because it has been found that lime treatment enhances the sludge settling characteristics (44). Further dewatering may be achieved by vacuum filtration. Ultimate disposal of the sludge, depending on land availability and other factors, would be by landfill or land application. Therefore preliminary screening indicates that four treatment systems may be applicable for handling CSO residuals. All involve lime stabilization but the degree of intermediate treatment, prior to disposal cannot be estimated at this point. Individual transportation and storage costs must be considered to establish which of these general alternatives is most cost-effective.

IMPACT OF HANDLING CSO SLUDGES AT VARIOUS SITES IN THE CITY

General

When considering separate treatment of CSO sludges by any of the chosen handling schemes, it is necessary to establish the location at which the sludge will be treated. There are three potential locales: treatment at parallel facilities at the dry-weather treatment plant; treatment at a central location and treatment at remote satellite locations.

A natural basis for selection of the location for CSO sludge treatment is the CSO treatment method used for treatment of the raw CSO. The physical, physical-chemical, and biological processes used on storm flows each have limitations as to where they can be used (9). Biological treatment facilities should be located at sewage treatment plants to provide a continuous active biomass. Physical and physical-chemical treatment facilities lend themselves more easily to remote satellite locations. Inasmuch as the CSO sludges from biological treatment will be treated both "on-site" and "at parallel facilities at the DWF plant", the question arises as to which alternative to use for treatment of the CSO sludges from physical and physical-chemical treatment.

Treatment of CSO Residuals at Parallel Facilities at the Dry-Weather Plant

Handling these CSO sludges in additional parallel facilities at the dry-weather plant does not appear to be generally feasible because of the problems involved in transporting the sludges from the CSO treatment site to the dry weather treatment plant. Alternative means for transporting the sludges to the parallel facilities at the dry-weather plant include bleed/

pump-back to the combined sewers, transport by separate pipeline and hauling. It is apparent from previous discussion that sludge bleed/pump-back to existing combined sewers would not be feasible in most cases because it would require storage, the sludge would be admixed with the sewage contributing to an overload on the dry-weather plant and grit in the sludge may settle out quickly in the interceptor causing blockage and premature overflow via backwater effect.

Separate pipeline transportation of sludges, say from remote overflow treatment points, would not appear to be feasible since it would require separate pipelines from many treatment points to the dry-weather plant which would appear to be costly. Moreover, because the flows through these lines are intermittent, grit and other solids deposits can accumulate between storms increasing pluggage problems. It may be possible to partially alleviate these accumulations by flushing the lines, however, this procedure may cause hydraulic overload problems at the treatment plant due to large volumes of water needed. In addition, the characteristics of the wastewater is extremely different from typical influent, and may adversely affect plant operation. However, where the CSO treatment facilities are centrally located near the dry-weather plant, pipeline transportation of CSO treatment sludges to parallel sludge treatment facilities at the dry-weather plant may be a viable alternative in spite of potential problems.

Similarly, hauling of CSO treatment sludges to parallel treatment facilities at the dry-weather plant may be feasible in isolated instances, but would not appear to be generally feasible because of the cost involved and the logistics for a trucking operation from many remote overflow points.

Utilization of pipeline transportation and hauling for bringing CSO sludges to the dry-weather plant may be enhanced if the major portion of the grit and inorganic solids were removed on-site at the overflow treatment facility and if subsequently the sludges were treated by digestion (aerobic or anaerobic) in parallel facilities which were kept viable between storms with dry weather sludge. If transportation of CSO sludges by bleed/pump-back, pipeline or hauling to the parallel sludge handling facilities at the dry-weather plant is not feasible, as is indicated from previous discussion, then the other alternatives must be considered.

Treatment of CSO Residuals at Centrally Located Sludge Handling Facilities

This alternative involves transportation of the CSO treatment residuals to a central location for stabilization, storage and further dewatering. All of the disadvantages associated with transport of the sludge to parallel dry-weather facilities are applicable with the exception of bleed/pump-back, which may not be possible. There may be some additional difficulty associated with obtaining sufficient property for locating the treatment plant, since in most areas of the country the combined sewers are located in the center of the city. This may possibly be a prohibitive factor in utilizing the

central location alternative. If property is scarce and if transportation using separate pipelines, or hauling is not feasible, as was indicated in the previous section, then on-site treatment of CSO sludge is the only remaining alternative. This choice is not without problems, such as the operation and maintenance of several solids handling plants at different remote locations in a city, but does have the advantage in that it eliminates the operational problems and cost associated with transporting the sludges from the remote CSO treatment sites to the dry weather plant.

Treatment of CSO Residuals at Satellite Treatment Sites

The remaining alternative to consider is therefore treatment of the CSO residuals at separate sites throughout a city. It is necessary to evaluate the effect of this handling with respect to performance, operation, maintenance and cost (9). The disadvantage of maintaining and operating several treatment systems is obvious with respect to both manpower and utilities costs. In addition, capital equipment costs are anticipated to be greater since the typical economics of scale can not be fully utilized. However, overall evaluation is necessary before this alternative can be implemented or disregarded.

The following discussion is pertinent to and limited to CSO treatment facilities at remote satellite locations. In this regard, and as previously noted, physical, physical-chemical and biological treatment processes used on storm flows each have limitations as to where they can be applied. Biological treatment systems should be located at sewage treatment plants which can supply a continuous active biomass. On the other hand, physical and physical-chemical treatment processes lend themselves more easily to remote locations at overflow points, and it is these locations which are the subject of this discussion.

The question has been raised that if on-site treatment of residual sludges is performed as recommended, what effects on operation, performance and maintenance would occur due to the logistics of operating and maintaining several sludge handling facilities at different locations, say 5 to 10 or perhaps 100, by one municipality? It is evident that sludge handling and disposal is an integral part of a CSO treatment system and the effectiveness with which sludge handling is carried out influences the efficiency of treatment, operation and maintenance, and overall costs. Moreover, the effective operation of a total CSO treatment system requires not only the physical operation of the components (overflow treatment and sludge handling) but also their operation in unison and on-call. Therefore, the aspects of operation and maintenance for CSO treatment and residual sludge handling should be equally emphasized. These aspects include operating controls and options, sustaining (dry-weather) maintenance, support facilities and supply, and safety.

Storm events occur at random intervals, and for this reason it is essential that multiple remote treatment sites be capable of automatic startup and shutdown. Furthermore, the instrument and equipment reliability requirements may be much more demanding than for dry-weather treatment facilities.

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The lime stabilization process, for example, lends itself well to automation because two of the most important variables in the process are pH and contact time. Contact time may be adequately controlled by system design, and pH is relatively simple to control and automate.

It is indicated that a sustaining or preventative maintenance program is the one key to a successful combined sewer overflow pollution abatement and control system. The program begins with the careful planning and design of the combined sewer overflow treatment and solids handling facilities. For example, whenever several systems are needed, which is the primary thrust of this discussion, it is usually economical to use the same type device, equipment, and design to reduce operation and maintenance costs. Also, designing in increased automation permits minimization of cleanup and maintenance.

The performance of remote site facilities are greatly enhanced by strict adherence to a well-planned sustaining maintenance program. Generally, the sustaining maintenance required increases as the degree and complexity of treatment sophistication increases. Effective control and operation of such facilities are usually dependent upon varying degrees of instrumentation. For example, to ensure reliable startup and shutdown, all instrumentation must be checked and calibrated on a regular basis.

Satisfactory operation of combined sewer overflow abatement and treatment facilities depends, to a large extent, on adequate regular inspection and maintenance. The purpose of this is twofold: first, to locate and correct any operational problems or failures and second, to prevent or reduce the probability of such problems or failures.

Inspection should be as frequent as necessary to keep such facilities in good operating condition. Generally, this means inspections both on a weekly schedule and following each major storm. All equipment must be exercised regularly to check and insure readiness, and facility cleanup, lubrication and dewatering must be done following each storm.

Complete records should be kept of all inspection and maintenance. The time and date of each inspection should be recorded, together with a description of the condition of the equipment and the work performed. The number of man-hours spent on each piece of equipment should be noted. These data should be tabulated for each piece of equipment requiring excessive maintenance or that is out of service with unusual frequency. These records can provide the data needed to compare the cost and efficiency of different types of equipment for guidance in the design and purchase of new equipment or the remodeling of existing equipment. Such records also aid in the scheduling of preventive maintenance. Required maintenance common to most off-line facilities may include lubricating of equipment; inspecting and cleaning of chemical pumps, electrical and pneumatic sensing probes, flow measuring and recording devices, and automatic samplers; checking and calibrating instruments; checking emergency power generators and starting batteries; and inspecting all pumps, valves, and piping.

The importance of maintenance support in the operation of treatment facilities increases as the number and/or size of such facilities increases. In view of the wide variety of control and treatment processes, no attempt will be made to cover the specific requirements of each individual process; only the common general requirements will be listed. The four major requirements are (1) access to equipment, (2) adequate tools and equipment, (3) a specialized work area, and (4) spare parts stock.

Finally, storm flow management applications expose personnel to very real and very dangerous environmental conditions. The hazards are a function of the working environment, operating procedures and practice, and condition and design of facilities. The chemicals used or stored present another problem because of their toxicity, corrosiveness, etc. Plant features, such as railings, kickboards, safety treads, multiple access/egress points, ventilation, lighting, auxiliary power sources, and detection and observation points, must be fully incorporated into design and practice.

In summary, the logistics of operating and maintaining several solids handling plants at different locations throughout a city is formidable but not insurmountable.

SECTION VII

CONSIDERATIONS FOR LAND
APPLICATION OF CSO WASTES

Land application of wastes, in general, entails the use of plants, the soil
surface, and the soil matrix for removal of certain pollutional constituents.
Land application systems can be considered as viable alternatives for waste
treatment and disposal.

However, the consideration of land for the treatment and disposal of any
type of waste is a very complex matter that encompasses a wide range of de-
sign possibilities which are available to suit specific site characteristics,
treatment requirements and project objectives. To date, no generalized de-
sign procedure is in use or available which would assist in evaluating the
major variables that influence the design of a land application system.
Therefore, the information in this section is intended to summarize the pre-
sent state-of-the-art technology and, from this knowledge, provide informa-
tion and criteria for evaluating the feasibility of applying CSO constituents
to. the land. The storm generated discharge residuals that will be con-
sidered for study include:

1. Raw CSO
2. CSO sludges, liquid and dewatered

The following discussions are primarily based on the following EPA Technical
Bulletins and Information Transfers: "Wastewater Treatment and Reuse by
Land Application" (45); "Land Treatment of Municipal Wastewater Effluents"
(46); "Evaluation of Land Application Systems" (47); "Costs of Wastewater
Treatment by Land Application" (48); and "Municipal Sludge Management:
Environmental Factors" (38).

LAND APPLICATION TECHNOLOGY

The inclusion of this technology section is to establish a general procedure,
based on an understanding of the pollutant management capabilities of soils,
for evaluating the feasibility of land application of CSO wastes under
various conditions. This development will provide a rational screening
method which should lead to 1) the identification of specific factors, 2) an
indication of the public health and legal constraints in using land applica-
tion, and 3) site locations that combine the required characteristics for
safe pollutant management. Essentially, the information presented in this
section includes state-of-the-art discussions of the following areas: land

application methods, public health considerations, imposed government regulations, site selection and factors, and design considerations.

Land Application Methods

The three basic methods of land application are irrigation, infiltration - percolation, and overland flow. Each method, shown schematically in Figure 9, can produce renovated waters of different quality, can be adapted to different site conditions, and can satisfy different overall objectives. Tables 32 and 33 compare major design and operational characteristics employed for these application systems. Relevant characteristics, including factors involved in selection and design of land application systems, will be briefly reviewed in this text.

Irrigation - Irrigation is the most widely used method of land application in practice today. The controlling factors in implementing this type of land application system are site selection and design, methods of irrigation, loading constraints, management and cropping practices, and the expected treatment or removal of pollutional constituents.

Important factors involved in site selection are: type, drainability and depth of soil; the nature, variation of depth and type of underground formation; topography; and considerations of present and future land use trends. Climate is equally as important as the land in the design and operation of irrigation systems. However, climate is not a design variable since it is specific to regions under consideration.

Table 34 lists major factors and generalized criteria for site selection. Soil drainability is considered the primary factor because, coupled with the type of crop or vegetation selected, it directly affects the hydraulic loading rate. The ideal geological formation is a moderately permeable soil capable of infiltrating approximately 5 cm per day (2 in/day) or more on an intermittent basis. In general, soils ranging from clay loams to sandy loams are suitable for irrigation. Soil depth should be a minimum of 0.6 meters (2 ft) of homogenous material and preferably 1.5 to 1.8 m (5-6 ft) throughout the site. This depth is necessary to promote extensive root development of some plants, as well as for wastewater treatment.

The minimum depth to groundwater should be 1.5 m (5 ft) to ensure aerobic conditions. Control procedures, such as underdrains or wells, may be required if the groundwater is within 3 to 6 meters (10-20 ft) of the surface and site drainage is poor.

For crop irrigation, slopes should be limited to about 10 percent or less, depending upon the type of harvesting equipment to be used. Densely foliated hillsides, up to 30 percent in slope, have been spray irrigated successfully.

Spray, ridge and furrow, and flood are three of the most common methods of irrigating. Spray irrigation is accomplished using a variety of systems from portable to solid-set sprinklers. Ridge and furrow irrigation consists

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EVAPORATION

SPRAY OR
SURFACE
APPLICATION

CROP

ROOT ZONE

SLOPE
VARIABLE

DEEP
PERCOLATION

SUBSOIL

a. IRRIGATION

EVAPORATION

SPRAY OR SURFACE
APPLICATION

INFILTRATION

PERCOLATION THROUGH
UNSATURATED ZONE

ZONE OF AERATION
AND TREATMENT

RECHARGE MOUND

OLD WATER TABLE

b. INFILTRATION-PERCOLATION

EVAPORATION

SPRAY APPLICATION

GRASS AND VEGETATIVE LITTER

SHEET FLOW

SLOPE
0.6-1.2m

PERCOLATION

RUNOFF
APPLICA-
TION

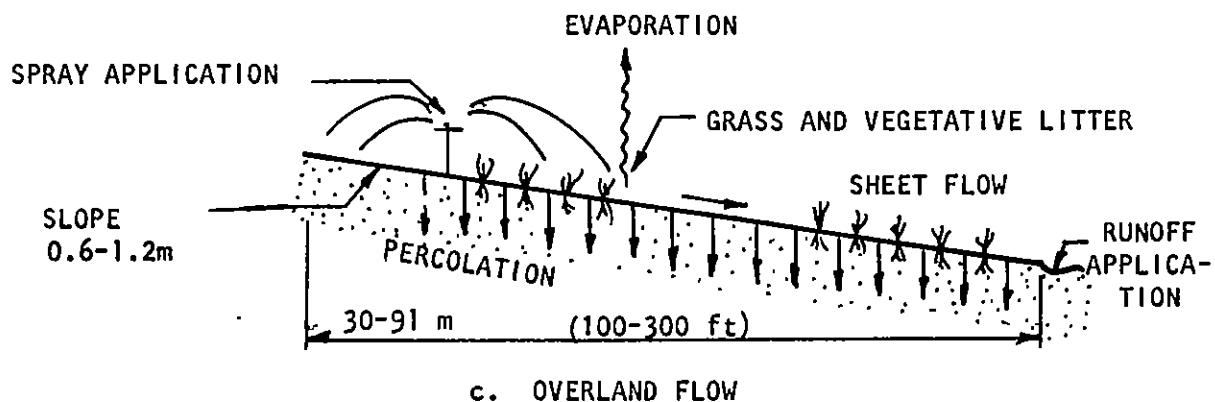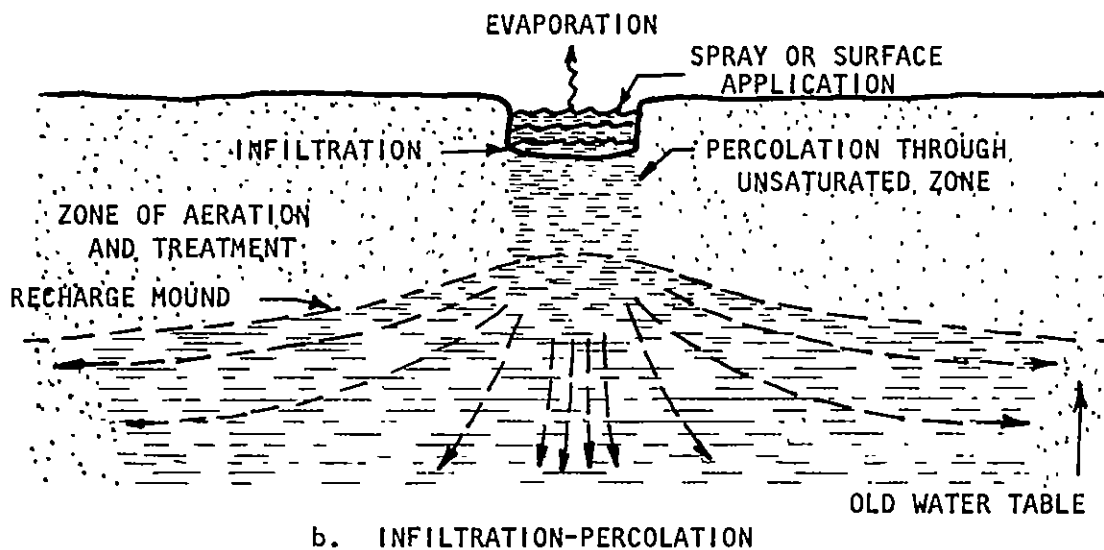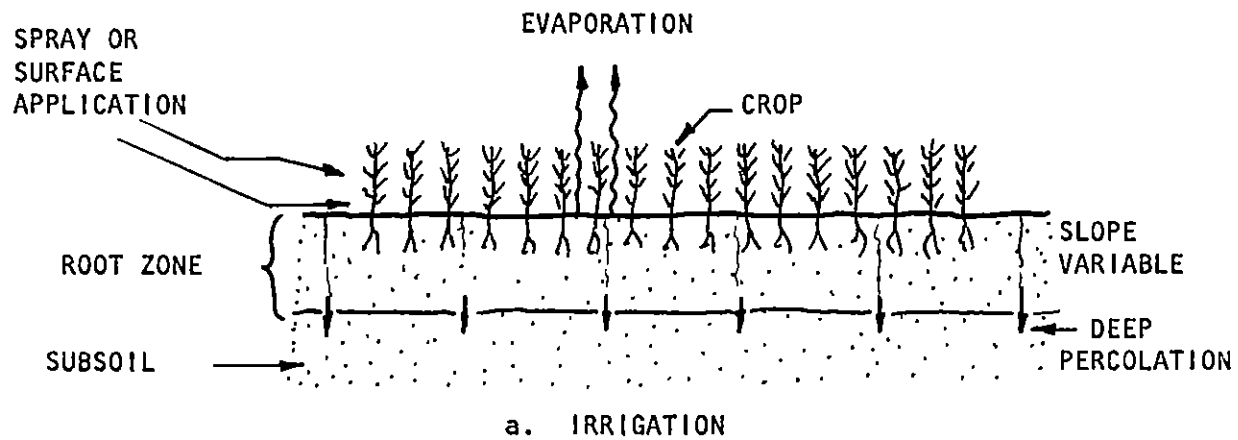30-91 m   (100-300 ft)

c. OVERLAND FLOW

Figure 9. Methods of land application (47).

TABLE 32. COMPARATIVE CHARACTERISTICS OF
IRRIGATION, INFILTRATION-PERCOLATION, AND
OVERLAND FLOW SYSTEMS (48)

| Factor | Irrigation | | Infiltration-percolation | Overland flow |
	Low-rate	High-rate		
Liquid loading rate, in./wk	0.5 to 1.5	1.5 to 4.0	4 to 120	2 to 9
Annual application, ft/yr	2 to 4	4 to 18	18 to 500	8 to 40
Land required for 1-mgd flowrate, acres[a]	280 to 560	62 to 280	2 to 62	28 to 140
Application techniques	Spray or surface		Usually surface	Usually spray
Vegetation required	Yes	Yes	No	Yes
Crop production	Excellent	Good/fair	Poor/none	Fair/poor
Soils	Moderately permeable soils with good productivity when irrigated		Rapidly permeable soils, such as sands, loamy sands, and sandy loams	Slowly permeable soils, such as clay loams and clays
Climatic constraints	Storage often needed		Reduce loadings in freezing weather	Storage often needed
Wastewater lost to:	Evaporation and percolation		Percolation	Surface runoff and evaporation with some percolation

(continued)

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TABLE 32. (continued)

Factor	Irrigation		Infiltration-percolation	Overland flow
	Low-rate	High-rate		
Wastewater lost to:	Evaporation and percolation		Percolation	Surface runoff and evaporation with some percolation
Needed depth to groundwater	About 5 ft		About 15 ft	Undetermined
Probability of influencing groundwater quality	Moderate		Certain	Slight

a Dependent on crop uptake

Metric conversion: in. x 2.54 = cm
ft x 0.305 = m
acre x 0.405 = ha

TABLE 33. COMPARISON OF IRRIGATION, OVERLAND FLOW,
AND INFILTRATION-PERCOLATION SYSTEMS (47)

Objective	Type of approach		
	Irrigation	Overland flow	Infiltration-percolation
Use as a treatment process with a recovery of renovated water[a]	0-70% recovery	50 to 80% recovery	Up to 97% recovery
Expected Treatment Performance:			
1. For BOD_5 and suspended solids removal	98+%	92+%	85-99%
2. For nitrogen removal	85+%[b]	70-90%	0-50%
3. For phosphorus removal	80-99%	40-80%	60-95%
Use to grow crops for sale	Excellent	Fair	Poor
Use as direct recycle to the land	Complete	Partial	Complete
Use to recharge groundwater	0-70%	0-10%	Up to 97%
Use in cold climates	Fair[c]	--[d]	Excellent

[a] Percentage of applied water recovered depends upon recovery technique and the climate.

[b] Dependent upon crop uptake.

[c] Conflicting data--woods irrigation acceptable, cropland irrigation marginal.

[d] Insufficient data.

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TABLE 34. SITE SELECTION FACTORS
AND CRITERIA FOR EFFLUENT IRRIGATION (45)

Factor	Criterion
Soil type	Loamy soils preferable but most soils from sands to clays are acceptable.
Soil drainability	Well drained soil is preferable; consult experienced agricultural advisors.
Soil depth	Uniformly 5 to 6 ft or more throughout sites is preferred.
Depth to groundwater	Minimum of 5 ft is preferred. Drainage to obtain this minimum may be required.
Groundwater control	May be necessary to ensure renovation if water table is less than 10 ft from surface.
Groundwater movement	Velocity and direction must be determined.
Slopes	Up to 15 percent are acceptable with or without terracing.
Underground formations	Should be mapped and analyzed with respect to interference with groundwater or percolating water movement.
Isolation	Moderate isolation from public preferable, degree dependent on wastewater characteristics, method of application, and crop.
Distance from source of wastewater	A matter of economics.

m = 0.305 x ft

of grooming relatively flat land into alternating ridges and furrows and applying water by gravity to these furrows. Flood irrigation is the inundation of land with several inches of wastewater.

The type of irrigation system to be used to maintain specified ground and surface water criteria depends on soil drainability, crop, topography, climate and economics. Preapplication treatment is provided for most irrigation systems, and a wide range of treatment requirements are encountered. The bacteriological quality of wastewater is usually limiting where food crops or landscape areas are to be irrigated, or where aerosol generation by sprinkling is of concern. In other cases, reductions in BOD and suspended solids may be necessary to prevent clogging of the distribution system, or to eliminate odor problems.

The important loading rates are hydraulic loading in terms of cm(inches) per week, and nitrogen loading in terms of kilograms per hectare per year (lbs/acre/yr). Organic loading rates are not considered important if an intermittent application schedule is followed. Hydraulic loadings should not exceed the infiltration capacity of the soil and may range from 1.3 to 10.7 cm per week (0.5-4.2 in./wk) depending on soil, crop, climate and wastewater characteristics. Typical hydraulic loadings are from 3.8 to 10.2 cm/wk (1.5-4.0 in./wk). Although irrigation rates have ranged up to 20.3 cm/wk (8 in./wk), a generalized division between irrigation and infiltration-percolation systems is 10.2 cm/wk (4 in./wk).

Nitrogen-loading rates have been considered because of nitrate occurrences in groundwaters and aquifers. To minimize such occurrences, application rates should be such that the total amount of plant available nitrogen added is no greater than twice the nitrogen requirement of the crop grown (38). In most cases, the permissible nitrogen loading rate will be the controlling factor.

Crop selection can be based on several factors: high water and nutrient uptake, salt or boron tolerance, market value, or management requirements. Popular crop choices are grasses with high year-round uptakes of water and nitrogen and low maintenance requirements. A drying period ranging from several hours each day to several weeks is required to maintain aerobic soil conditions. The length of time depends upon the crop, the wastewater characteristics, the length of the application period, and the texture and drainage characteristics of the soil. A ratio of drying time to wetting or application time of about 3 or 4 to 1 should be considered as a minimum.

Treatment of the wastewater often occurs after passage through the first 0.6 to 1.2 m (2-4 ft) of soil. Treatment efficiencies or removals are found to be on the order of 85 to 99 percent for BOD, suspended solids and bacteria (Table 35). Loamy soils with considerable organic matter have been found to almost completely remove heavy metals, phosphorus and viruses by adsorption and fixation. Nitrogen is taken up by plant growth, and if the crop is harvested, removals can be in the order of 90 percent.

Infiltration-Percolation - In this method, wastewater is applied to the soil by flooding or spraying onto basins and is treated as it percolates through

TABLE 35. REPORTED REMOVAL EFFICIENCIES OF LAND DISPOSAL AFTER BIOLOGICAL TREATMENT (47)

Constitutent	Removal efficiency, %		
	Irrigation	Infiltration-percolation	Overland flow
BOD	98+	85-99	92+
COD	80+	50+	80+
Suspended solids	98+	98+	92+
Nitrogen (total as N)	85+[a]	0-50[b]	70-90[a,b]
Phosphorus (total as P)	90-99	60-95	40-80[c]
Metals	95+	50-95[d]	50+
Microorganisms	98+	98+	98+[e]
TDS	+30-0[f]	+10-0[f]	+30-0[f]

a. Depends on crop uptake

b. Depends on denitrification

c. May be limiting

d. Ion exchange capacities may be limited

e. Chlorination of runoff may be needed

f. May increase

the soil matrix. Infiltration-percolation has been used with moderate load-
ing rates [10 to 30 cm/wk (4-12 in./wk)] as an alternative to discharging
effluent to surface waters. High-rate systems [1.53 to 2.44 m/wk (5-8 ft/
wk)] have been designed to recharge groundwater.

Soil drainability on the order of 10 to 30 cm/day (4-12 in./day) or more is
necessary for successful use of the infiltration-percolation approach. Ac-
ceptable soil types include sand, sandy loams, loamy sand, and gravel. Very
coarse sand and gravel are less desirable because they allow wastewater to
pass too rapidly through the first few feet where the major biological and
chemical action takes place.

Important criteria for site selection include high percolation rates; depth,
movement, and quality of groundwater; topography; and underlying geologic
formations. To control the wastewater after it infiltrates the surface and
percolates through the soil matrix, the hydrogeologic characteristics must
be known. Recharge should not be attempted without specific knowledge of
the movement of the water in the soil system.

Preapplication treatment is generally provided to reduce the suspended solids
content and thereby allow the continuation of high application rates. Dis-
infection is often provided prior to spreading or ponding to control bac-
teriological quality.

Depending on wastewater characteristics and water quality objectives, load-
ings of nitrogen, phosphorus, organic, or trace elements may be critical.
Although hydraulic or nitrogen loading is most often limiting, loadings of
salts and heavy metals may be critical in some cases. Loading schedules
that include alternating loading and resting periods are required to main-
tain the infiltration capability of the soil surface and to promote optimum
BOD and nitrogen removals by aerobic-anaerobic conditions.

In most cases, the filtering and straining action of the soil is extremely
effective, so suspended solids, bacteria, and BOD are almost completely re-
moved (Table 35). Nitrogen removals are generally poor unless specific
operating procedures are established to maximize denitrification. Phospho-
rus removals range from 70 to 90 percent, depending on the percentage of
clay or organic matter in the soil matrix which will adsorb phosphate ions.

The useful life of an infiltration-percolation system will be less than that
of irrigation or overland flow. This is a result of unacceptably high load-
ings of inorganic constituents, such as phosphorus and heavy metals which
are fixed in the soil matrix and not positively removed. Once the fixation
capacity for phosphorus and heavy metals have been exhausted, removal effi-
ciencies will deteriorate.

Management practices important to infiltration-percolation systems include
maintenance of hydraulic loading cycles, basin surface management, and
system monitoring. Intermittent application of wastewater is required to
maintain high infiltration rates, and the optimum cycle between inundation
periods and resting periods must be determined for each individual case.

Basin surfaces may be bare or covered with gravel or vegetation. Each type of surface requires some maintenance and inspection for satisfactory operation. Monitoring of groundwater levels and quality is essential to system management.

Overland Flow - In this method, wastewater is applied on the upper reaches of sloped terraces of relatively impermeable soils and allowed to flow across the vegetated surface to runoff collection ditches. Renovation is accomplished by physical, chemical and biological means as the wastewater flows in a sheet through the vegetation. A high percentage of the applied water is collected as runoff at the bottom of the slope, with the remainder being lost to evapotranspiration and percolation.

Important factors in overland flow are site selection, application rates and design loadings, management practices, and expected removal efficiencies. If the collected runoff is to be discharged into a navigable water, it will have to meet the stream discharge criteria.

Criteria important for site selection include: soil conditions, topography and climate. Soil conditions is perhaps the most important. Soils with minimal infiltration capacity, such as clays, clay loams and soils underlain by impermeable lenses are best suited for this method. However, a mantel of 15 to 20 cm (6-8 in.) of good topsoil is desirable. The land should have a slope of between 2 and 6 percent, so that the wastewater will flow as a sheet over the ground surface. Grass is planted to reduce soil erosion and to provide a habitat for the microbial flora which help purify the waste-water.

Since groundwater will not likely be affected by overland flow, it is of minor concern in selection. However, the groundwater table should be deeper than 0.6 m (2 ft) to insure aerobic conditions for plant growth.

When overland flow is used as a secondary treatment process, the minimum preapplication treatment is screening and possibly grit and grease removal to avoid clogging of the distribution system. Disinfection prior to appli-cation may avoid post-disinfection and allow spraying at higher pressures.

Overland flow systems are generally designed on the basis of hydraulic load-ing rates, although an organic loading rate or detention time might be the limiting criteria. The treatment process is essentially biological, requir-ing a minimum contact time between soil microorganisms and applied waste-water for adequate removals. Liquid application rates used in design have ranged from 6 to 14 cm/wk (2.4-5.5 in./wk), with a typical loading being 10 cm/wk (4 in./wk).

Treatment of wastewater by overland flow is only slightly less efficient than that by irrigation (Table 35). Results from field demonstration proj-ects have suggested BOD and suspended solids removals of 95 to 99 percent, nitrogen removals of 70 to 90 percent, and phosphorus removals of 50 to 60 percent. Solids and organics are removed by biological oxidation of the solids as they pass through the vegetative mat. Nutrients are removed

mainly by crop uptake. Removal mechanisms for other waste constituents include biological uptake and transformations and adsorption and fixation in the soil. Management practices important in overland flow are: maintaining the proper liquid application and resting cycles; maintaining an active biota and a growing grass; and monitoring the performance of the system. Hydraulic loading cycles have been found to range from 6 to 8 hours of spraying followed by 6 to 18 hours of drying. Cropping practices are necessary to stimulate growth and subsequent nutrient uptake. Monitoring of loading cycles is needed to achieve maximum removal efficiencies.

Public Health Considerations

The passing of the Federal Water Pollution Control Act Amendments of 1972 has focused attention on the public health aspects of land application of wastes. Consequently, the impact of land application on the environment, including public health, social and legal aspects, will be regulated by state and federal agencies.

Potential public health problems are attributed to (a) transmission of pathogens, (b) groundwater quality, (c) crop contamination, and (d) insect propagation. Generally, state health regulations and guidelines serve to protect against many of these potential public health problems.

The concern for pathogen survival and transmission involves aerosols, runoff and leachates from waste application. The danger of spray aerosols lies in their potential for transmitting pathogens which could conceivably be inhaled or contaminate adjacent lands. Aerosol travel and pathogen survival and transmission are dependent on several factors, including wind, temperature, humidity, and vegetative screens. In order to reduce pathogen transmission from spray-irrigated aerosols, some safeguards can be employed. Among these are disinfection, sprinklers that spray horizontally or downward with a low nozzle pressure, and adequate buffer or vegetative screening zones.

Survival times of various organisms in soil, water and vegetation have been extensively reported in the literature (46). The survival of pathogenic organisms in the soil can vary from days to months, depending on the soil moisture, temperature, and type of organisms. In relation to survival of coliform organisms, some bacteria do survive for a longer time in soil. The survival of viruses in soil is essentially unexplored.

Contamination of groundwater is another public health aspect that must be considered. In most cases, a sufficient degree of renovation will be required to meet the best practicable treatment requirements for groundwater protection. EPA regulations on National Primary Drinking Water Standards, listed in Table 36, impose groundwater quality guidelines upon land application systems. Nitrates are the most common concern, but other constituents, including stable organics, dissolved salts, trace elements, and pathogens should be considered. Thus, proper management practices and extensive monitoring programs are necessary to comply with regulatory restrictions.

TABLE 36. NATIONAL PRIMARY DRINKING WATER STANDARDS (49)

Constituent or characteristic	Value	Reason for standard
Physical:		
Turbidity, units	1[a]	Aesthetic
Chemical, mg/l:		
Arsenic	0.05	Toxic
Barium	1.0	Toxic
Cadmium	0.01	Toxic
Carbon chloroform extract	0.7	Toxic
Chromium, hexavalent	0.05	Toxic
Cyanide	0.2	Toxic
Fluoride	1.4-2.4[b]	Toxic
Lead	0.05	Toxic
Mercury	0.002	Toxic
Nitrates as N	10	Toxic
Selenium	0.01	Toxic
Silver	0.05	Cosmetic
Bacteriological:		
Total coliform, per 100 ml	1	Disease
Pesticides, mg/l:		
Chlordane	0.003	Toxic
Endrin	0.0002	Toxic
Heptachlor	0.0001	Toxic
Heptachlor Epoxide	0.0001	Toxic
Lindane	0.004	Toxic
Methoxychlor	0.1	Toxic
Toxaphene	0.005	Toxic
2,4-D	0.1	Toxic
2,4,5-TP	0.01	Toxic

[a] 5 mg/l may be substituted if it can be demonstrated that it does not interfere with disinfection.

[b] Dependent upon temperature, higher limits for lower temperatures

Another public health consideration for the land disposal site is maintaining crop quality with regards to safety for consumption. Many states have regulations dealing with the types of crops that may be irrigated with wastewater, degrees of preapplication treatment required for various crops, and purposes for which the crops may be used.

Propagation of mosquitoes and flies, poses a health hazard as well as a nuisance condition. Mosquitoes are known vectors of several diseases. Mosquitoes may increase in population because of the wetter environment and the availability of standing puddles for breeding (50). For these reasons a mosquito control program may be required as part of the land disposal site operation.

Government Regulations

On a nationwide basis, the Federal Water Pollution Control Act Amendments of 1972, PL92-500, has been responsible for the renewed interest in land application of wastes. PL92-500 places emphasis on waste management alternatives which are cost-effective; utilize the best practicable treatment technology; and consider reuse and recycling of water and nutrient resources. Land application can comply with these recommendations. A preliminary bulletin (38) released by the EPA, addressed several factors which are important to the environmental assessment of a particular land application option, including considerations and guidelines for design.

Other laws which are pertinent to the practice of land application are the National Environmental Policy Act of 1969 (NEPA) and The Safe Drinking Water Act. NEPA requires the preparation of an environmental impact statement for all projects involving Federal funds. The Safe Drinking Water Act sets forth National Primary Drinking Water Standards which apply primarily to groundwater sources used for drinking water. Therefore, land application systems discharging to groundwater will be forced to meet these standards.

In general, the national requirement for land application of sludges to lands on which crops will or may be grown must be examined closely in terms of protecting public health and future land productivity. Sludges must be stabilized to reduce public health hazards and to prevent nuisance odor conditions. For some wastes, it may be necessary to achieve increased pathogen reduction beyond that attained by stabilization. Additionally, groundwater should be protected from pollution. Consideration should be given to the duration of the project, the quality of the groundwater, and if the groundwater is typically used for drinking water supplies with little or no additional treatment. Specific groundwater criteria for land application application systems are contained in the EPA publication, "Alternative Waste Management Techniques for Best Practicable Waste Treatment" (51).

State regulatory agencies have recognized the increasing interest in the land application alternative and thus, are developing regulations and guidelines concerning land application for use within their own boundaries. Twenty-six states have issued regulations or guidelines for this practice whereas five states are currently preparing guidelines. Of the remaining

states, design plans are approved on a case by case basis. At present, these regulations and guidelines vary according to local geography, climatology and economy of the states (52). However, similar restrictions can be observed for state land application guidelines because many of the states have used similar reference materials: "Great Lakes-Upper Mississippi River Board of State Sanitary Engineers - Recommended Standards for Sewage Wastes - Addendum #2" (53) and EPA's "Evaluation of Land Application Systems" (47).

Site Selection and Evaluation

The wide range of potential site characteristics greatly complicates any attempt to develop standardized evaluation criteria. Even so, initial planning concerns have some degree of commonality which include considerations for land use, climate, topography, groundwater, and soils and geology. The selection of a site location should include both the distance and elevation difference from the wastewater collection area. These factors will affect the feasibility and economics of the transmission of the waste to the site. Also, of significant importance in site selection is the compatibility of the intended use with regional land-use plans. Knowledge of current land-use in an area provides an indication of the quantity of land potentially available or suitable for waste application. A review of land use maps can avoid consideration of areas with conflicting features.

Prevailing climatic conditions will affect a large number of design decisions including; the method of land application, storage requirements, total land requirements, and loading rates. Relationships between climate and land application systems are shown in a generalized climatic map (Figure 10). The depicted zones are only useful in preliminary planning stages, since detailed analysis of local climatic data is essential for design purposes.

Zone A has a seasonal pattern of precipitation of about 38 to 64 cm (15-25 in.) during the months from November to April. Temperatures are mild in winter and hot in summer. Plant growth can continue through the year assuming irrigation is provided. Storage of effluent is not required for climatic reasons. Zone B covers the areas that are very hot and arid year round. Winter storage is not a major concern. Zone C includes the areas where precipitation is distributed throughout the year, with hot, humid summers and fairly mild winters. Year round operation of land application systems is possible in these areas. Zone D has moderately cold winters and hot summers. Precipitation is distributed throughout the year. Winter conditions are such that storage will often be required for periods up to 3 months. Zone E has precipitation occurring in all months of the year, averaging from 50 to 100 cm (20-40 in.) annually. Winter operations are severely limited due to low temperatures, ice and snow, thus requiring storage for periods up to six months.

The National Weather Service, local airports, and universities are potential sources of climatological data. Climatic factors of concern include precipitation, storm intensity, duration and frequencies, temperature, evapotranspiration, and wind velocity and direction. The data base should consider sufficient durations of time so that long-term averages and frequencies of extreme conditions can be established.

CLIMATIC ZONES

A   MEDITERRANEAN CLIMATE –
    DRY SUMMER – MILD, WET WINTER
B   ARID CLIMATE – HOT, DRY
C   HUMID SUBTROPICAL – MILD WINTER – HOT, WET SUMMER
    (WASHINGTON, OREGON AREA MILD, MOIST SUMMER)
D   HUMID CONTINENTAL – SHORT WINTER, HOT SUMMER
E   HUMID CONTINENTAL – LONG WINTER, WARM SUMMER

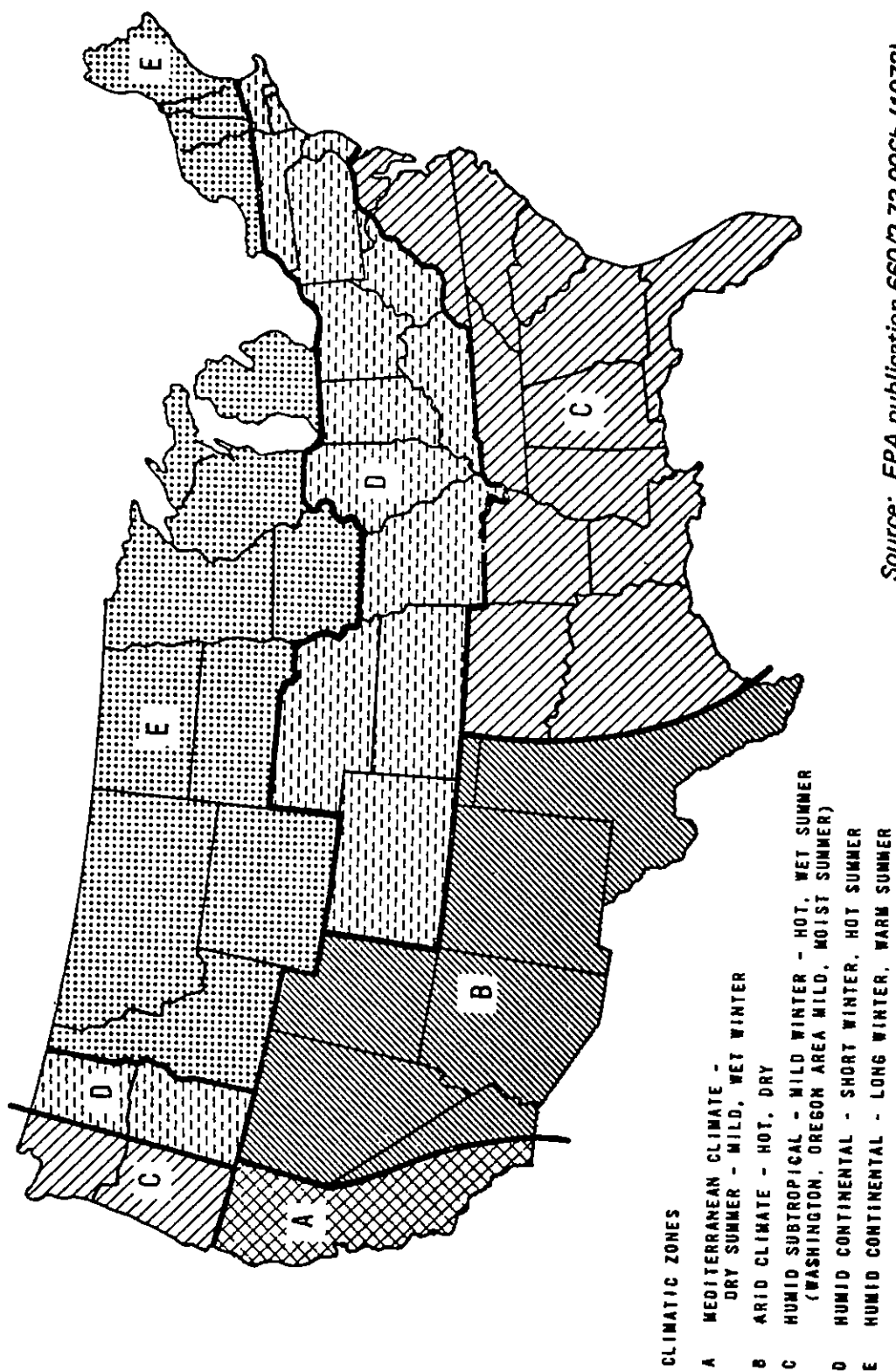*Source: EPA publication 660/2-73-006b (1973)*

Figure 10.   Generalized climatic zones for land application (45).

Topography affects both the water handling capability of a site and the extent of contact between waste constituents and soil particles. Examination of local and surrounding topography is useful in determining drainage patterns and flow rates of surface and subsurface water. Topographic maps, available from the USGS, are necessary for site selection and subsequent system design. Topographic information of concern includes ground slope, proximity of surface water, erosion and flood potential, and existing vegetative cover.

Soil properties determine the suitable waste application or loading rate, thereby affecting the amount of land required and the method of application. Thus, soil properties are often considered the most important factors in selecting both the site and the land application method. Properties that are important in describing and evaluating soils include soil texture, structure and profile, permeability, available water capacity, and chemical characteristics such as pH, salinity, nutrient levels and adsorption and fixation capabilities. Information on soil properties can be obtained from the National Cooperative Soil Survey, the Agricultural Extension Service and some state universities.

Groundwater characteristics are important considerations in selecting a particular site. The effect of groundwater levels on renovation capabilities and the effects of the applied waste on groundwater movement and quality should be extensively evaluated. Additionally, the depth to groundwater should be determined, along with an evaluation of the groundwater rate of flow and direction and the permeability of the aquifer. Information on these sources can be obtained from the U.S. Geological Survey or State Divisions of Water Resources.

Design Considerations

For most land application systems, vast numbers of design possibilities are available to suit specific site characteristics, treatment requirements and overall project objectives. The scope of factors that are commonly considered in the design process include: a) preapplication treatment requirements; b) storage requirements; c) climatic factors; d) pollutional loading constraints; e) land area requirements; f) crop selection and management; g) system components; h) site monitoring program; and i) cost-effectiveness. It should be recognized that since land application system designs are site specific, design criteria must be based on the actual conditions of the site and therefore cannot be generalized.

Preapplication Treatment Requirements - Treatment of wastes prior to land application may be necessary for a variety of reasons, including: 1) public health regulations, 2) loading constraints with respect to critical wastewater characteristics, and 3) the desired effectiveness and dependability of the system components. In areas where long-term winter storage is required, some degree of treatment may be necessary to prevent nuisance conditions during storage.

Public health considerations, pathogen transmission and groundwater quality are usually the most important factors in determining the required degree of